# Towards a more realistic representation of surface albedo in NASA CERES satellite products: a comparison with MOSAiC field campaign

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CERES Science Team Meeting

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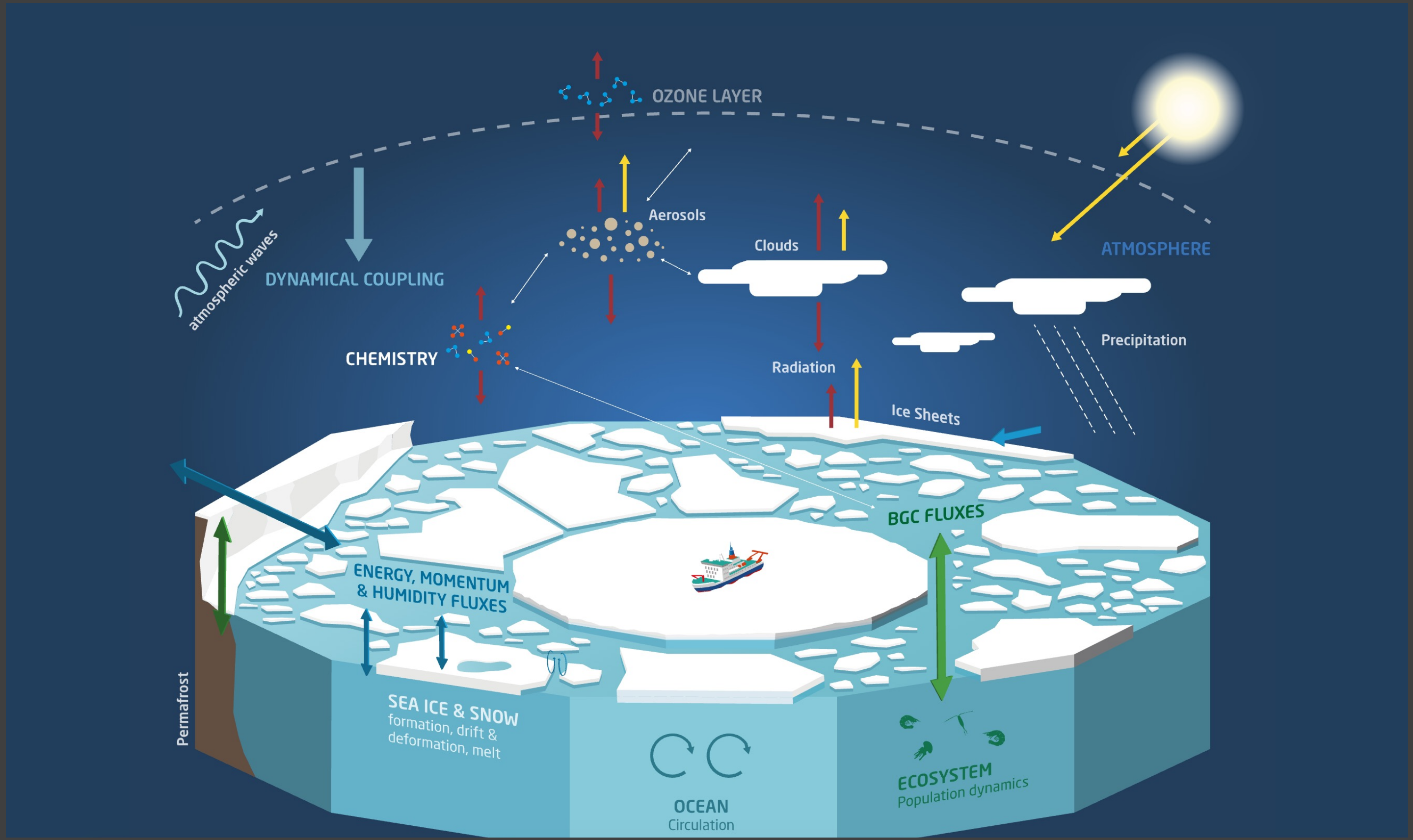
# The Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) field campaign

September 2019 - October 2020

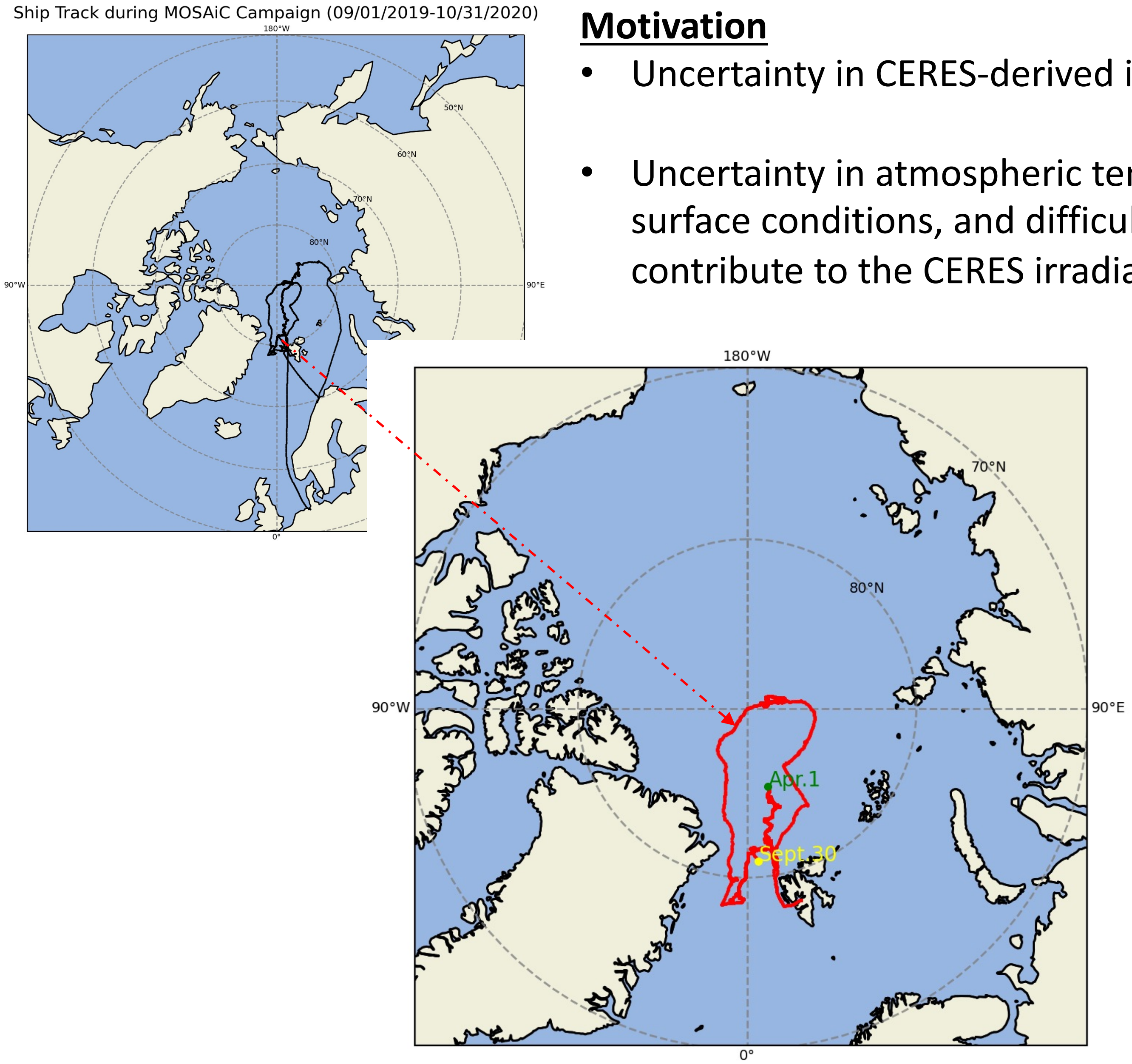
- The largest polar expedition in history; the first time in polar winter
- The goal of the MOSAiC expedition was to take the closest look ever at the Arctic as the epicenter of global warming and to gain fundamental insights that are key to better understand global climate change




https://mosaic-expedition.org/

# Overview




## Motivation

- Uncertainty in CERES-derived irradiances is larger over sea ice than any other scene type

- Uncertainty in atmospheric temperature and humidity from reanalysis, heterogeneity in surface conditions, and difficulties in detecting and characterizing clouds over sea ice all contribute to the CERES irradiance uncertainty

## Outline

- The comparison between CERES SYN1deg and MOSAiC from April to September 2020

- The surface albedo perturbation experiments with Fu-Liou radiative transfer model

# MOSAiC remote flux stations (managed by CIRES/NOAA)

- **Multiple remote flux stations**: asfs30, asfs40, asfs50
- **Temporal resolutions**: 10s
- **Location**: top of station at 2 m

**Measurements at surface**
solar zenith angle, solar azimuth angle, snow depth, air pressure, air temperature, relative humidity, dew point temperature, mixing ratio, absolute humidity, vapor pressure, brightness temp, surface skin temp, conductive flux, wind speed, wind direction

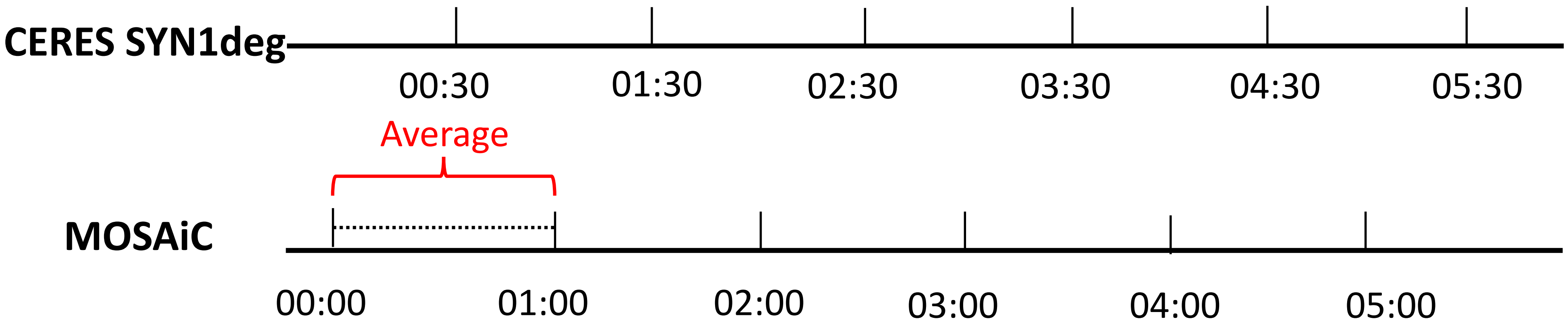
**Turbulence and met tower (2m, 6m, 10m, 24m)**
Latent heat flux, Sensible heat flux
Temperature

**Radiation measurements**

| Variable | Instrument |
|---|---|
| SW_up flux | Hukseflux SR30 pyranometer |
| SW_down flux | Hukseflux SR30 pyranometer |
| LW_down flux | Hukseflux IR20 pyrgeometer |
| LW_up flux | Hukseflux IR20 pyrgeometer |
| Net radiative flux | SR30 and IR20 radiometers |

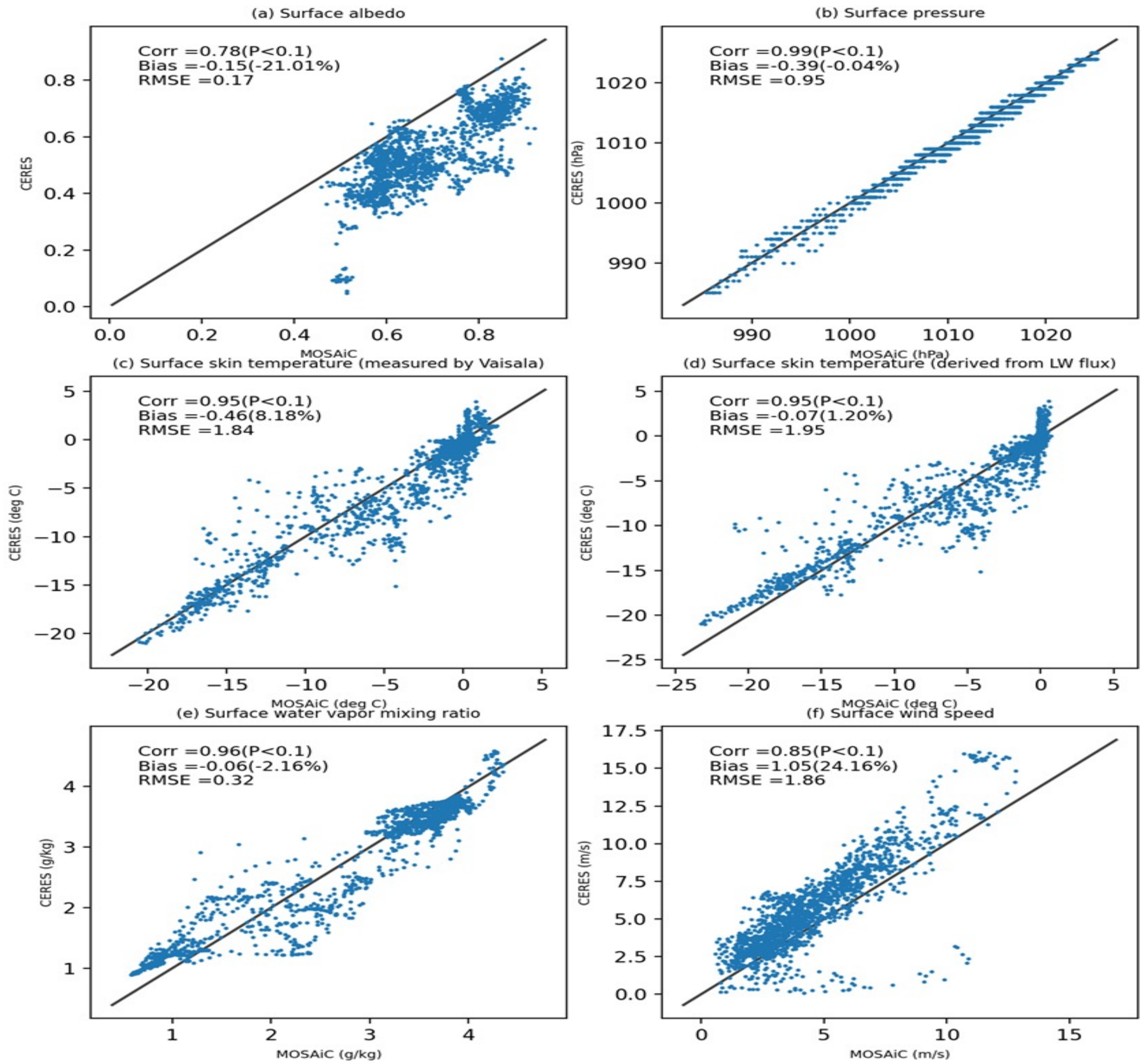
# Collocation between CERES SYN1deg and MOSAiC

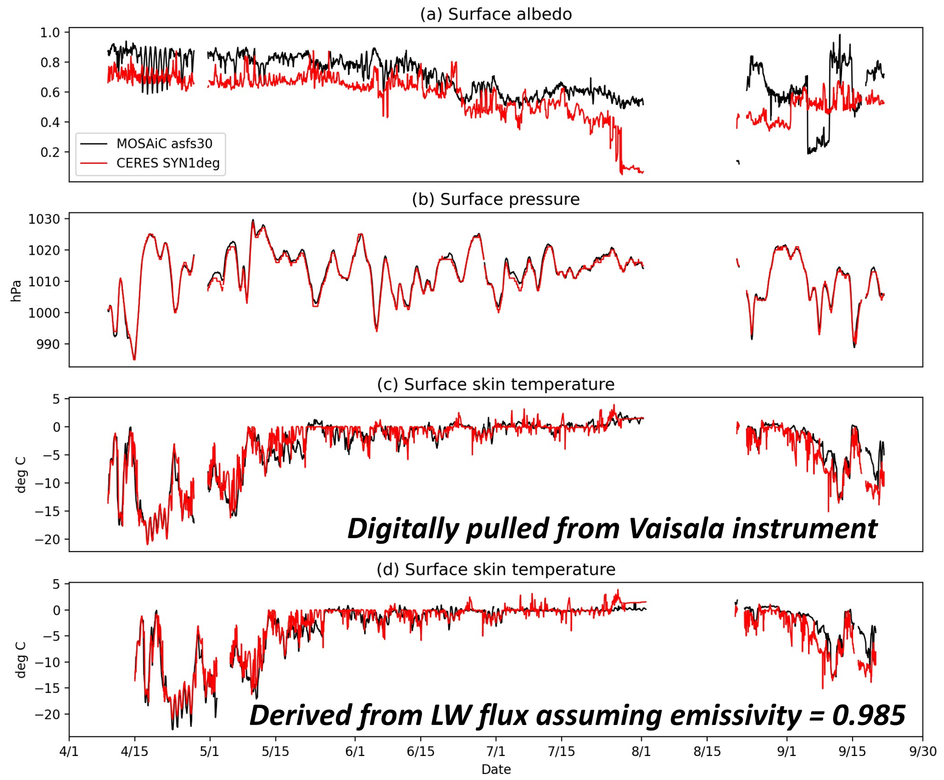
- **<u>CERES</u>**: CERES_SYN1deg-1H_Terra-Aqua-MODIS_Ed4.1 (Hourly)
- **<u>MOSAiC</u>**: mosasfsmet.level2.10min (10-min)
- Averaged 10-min MOSAiC data (location, radiative fluxes) and saved it as hourly output
- Collocated MOSAiC hourly data with CERES SYN1deg dataset by finding the closest grid box




- **<u>"Matched" surface sites</u>**: Subsequent analysis considers only days where at least two of the three stations collected data

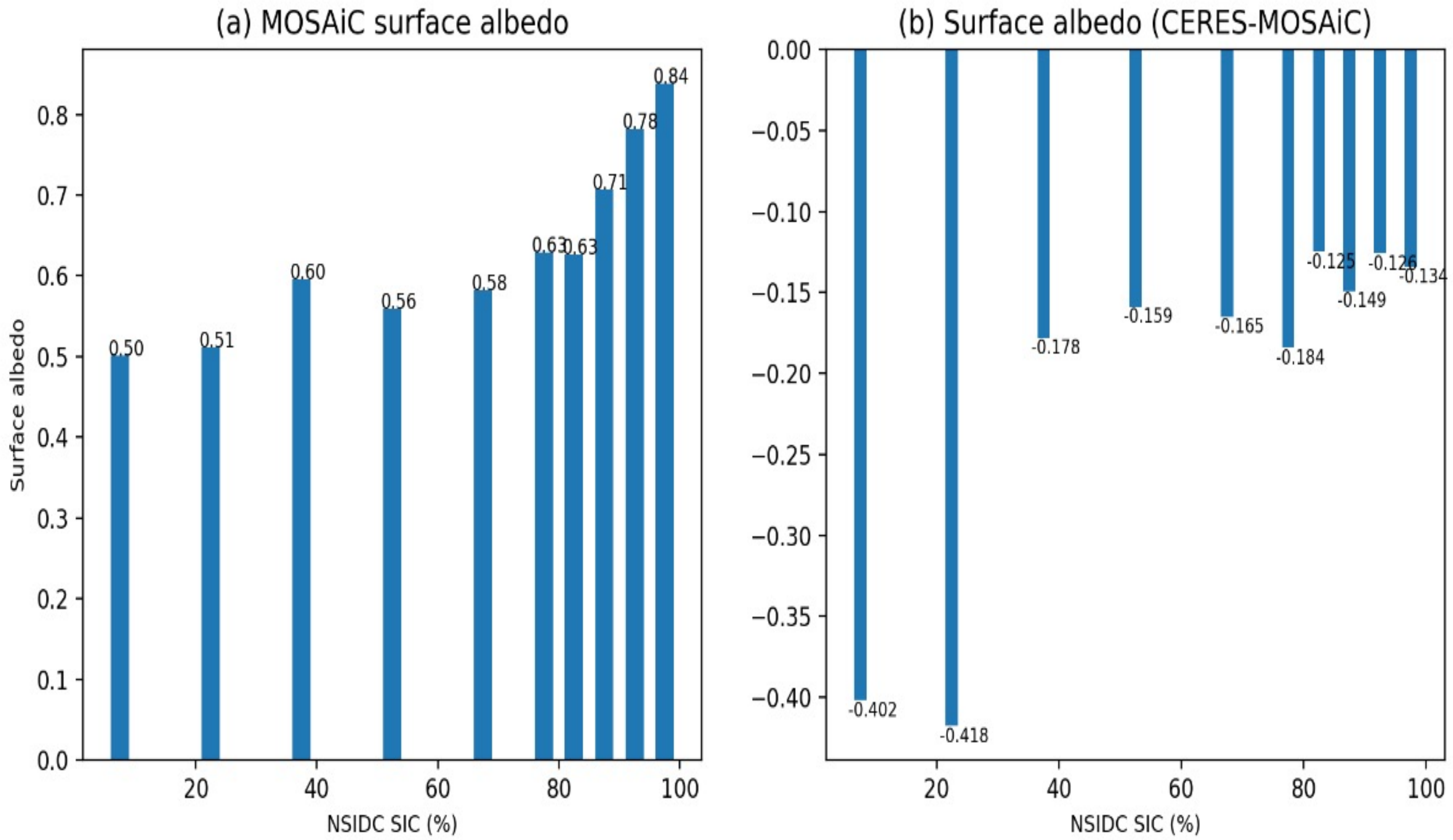
# Meteorological conditions: MOSAiC and CERES SYN1deg



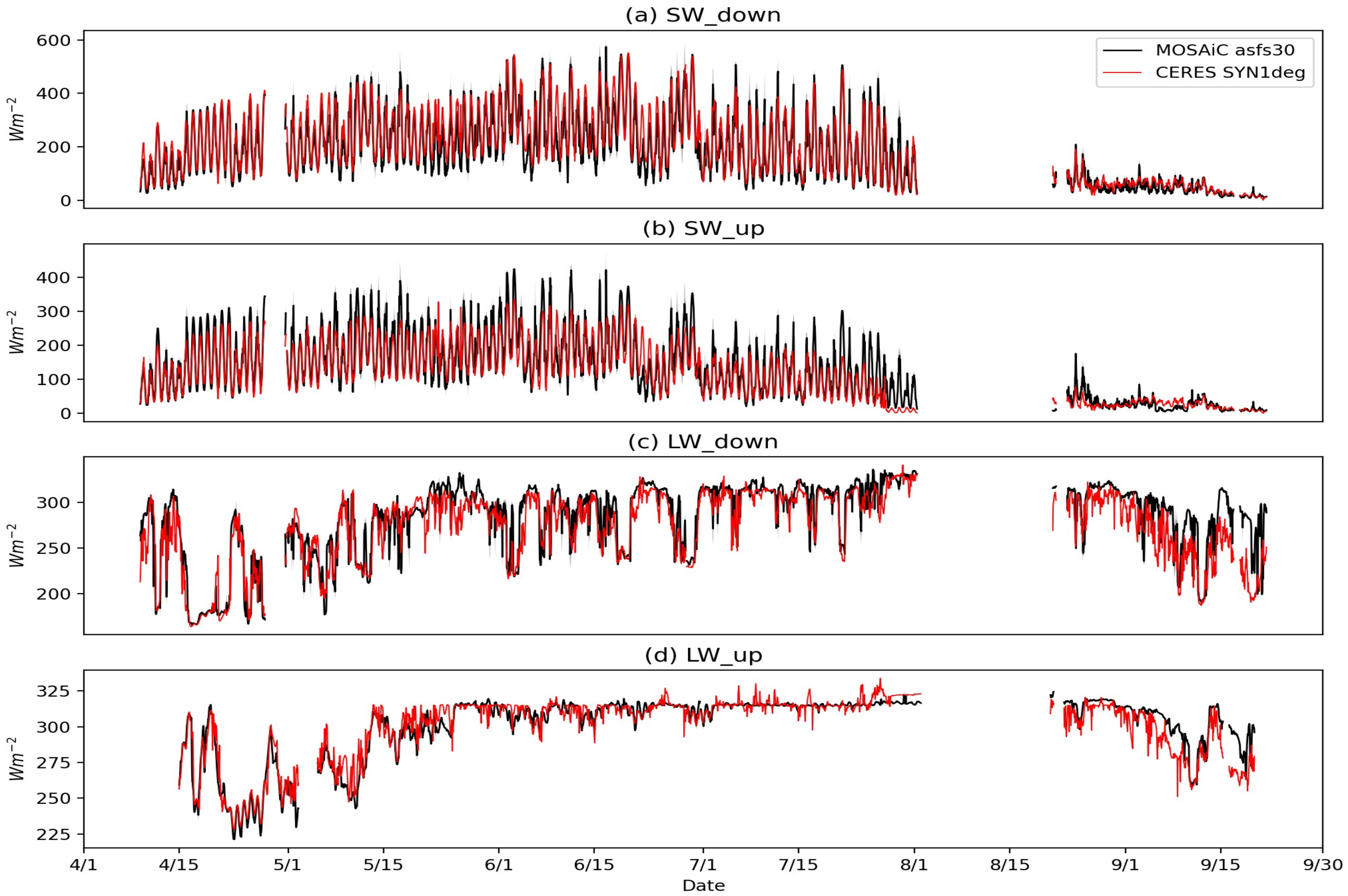

- The SYN1deg constantly underestimates the surface albedo during summertime
- Large uncertainty remains in surface skin temperature when surface reaches melting point (~0°C)

# Sea ice concentration dependent albedo differences: MOSAiC and CERES SYN1deg

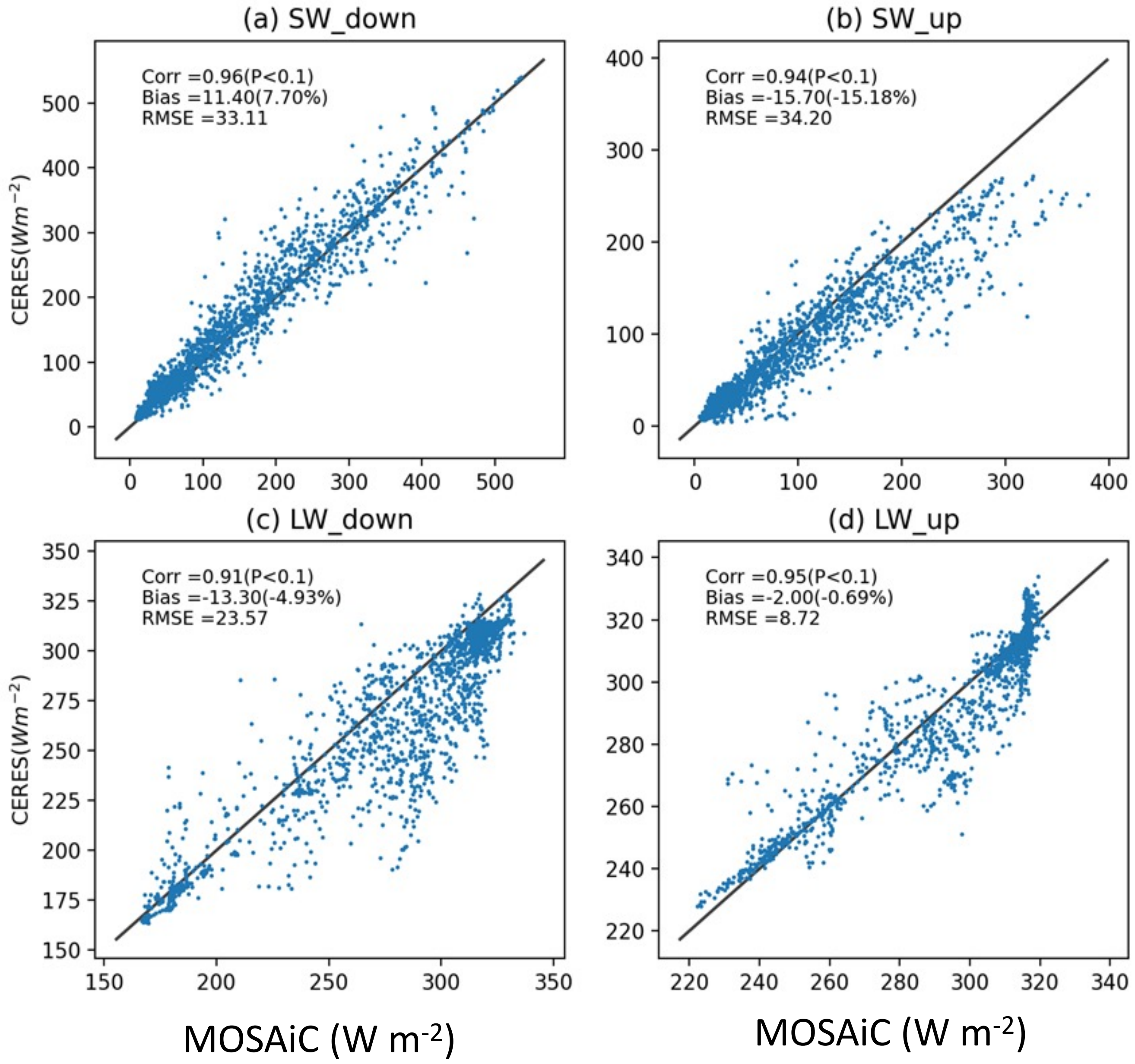



- CERES-MOSAiC differences in surface albedo are sea ice concentration dependent.
- Differences at lower sea ice concentrations is attributed to the smaller scale of the MOSAiC observations (~6 $m^2$ area), such that they only represent the sea ice portions of the CERES gridbox.

# Radiative fluxes at the surface: MOSAiC asfs30 and CERES SYN1deg



# Radiative fluxes at the surface: MOSAiC and CERES SYN1deg

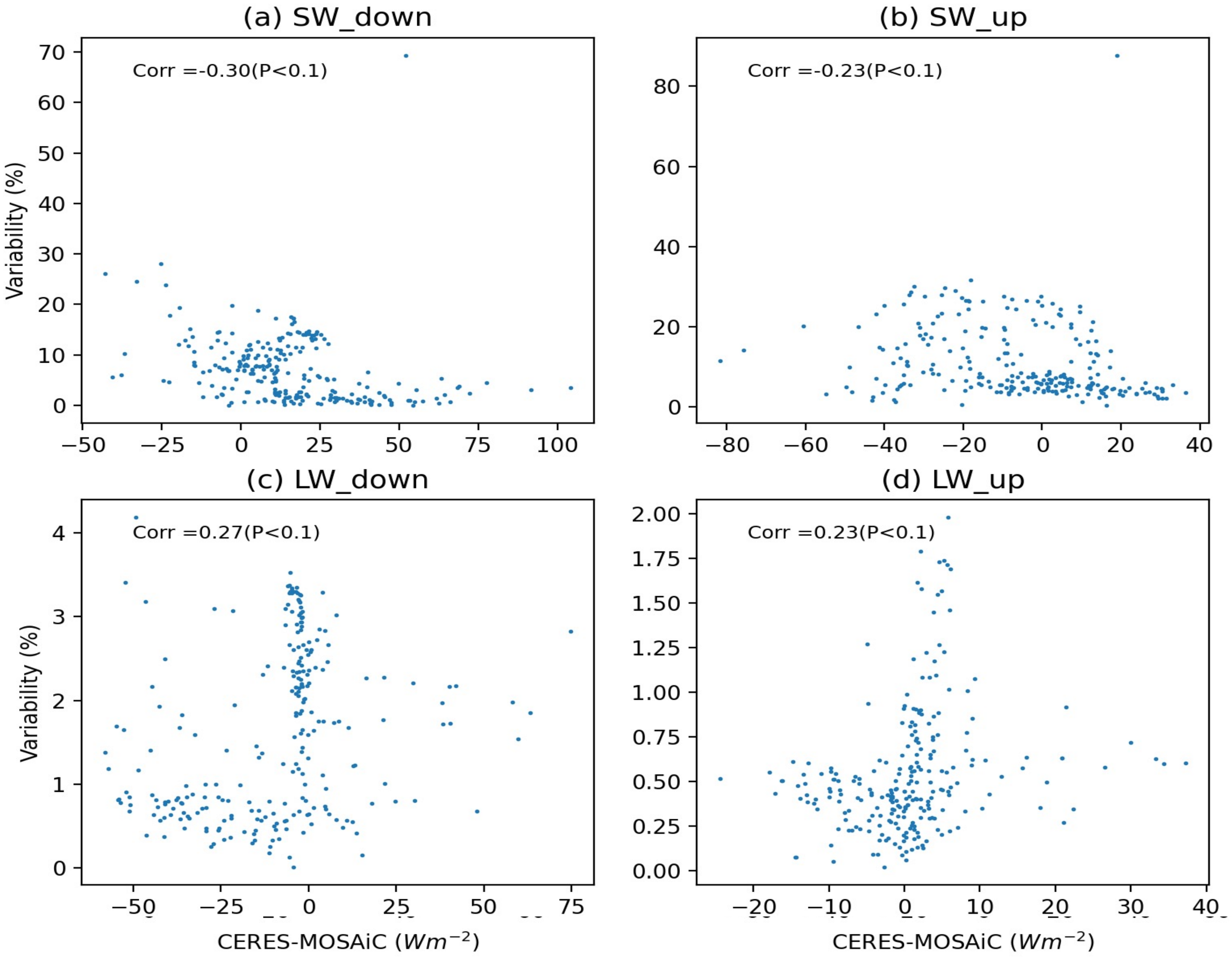



- The SYN1deg tends to overestimate SW_down flux, but underestimate SW_up and LW_down fluxes at the surface during summertime

- The SW_up flux is the most uncertain quantity

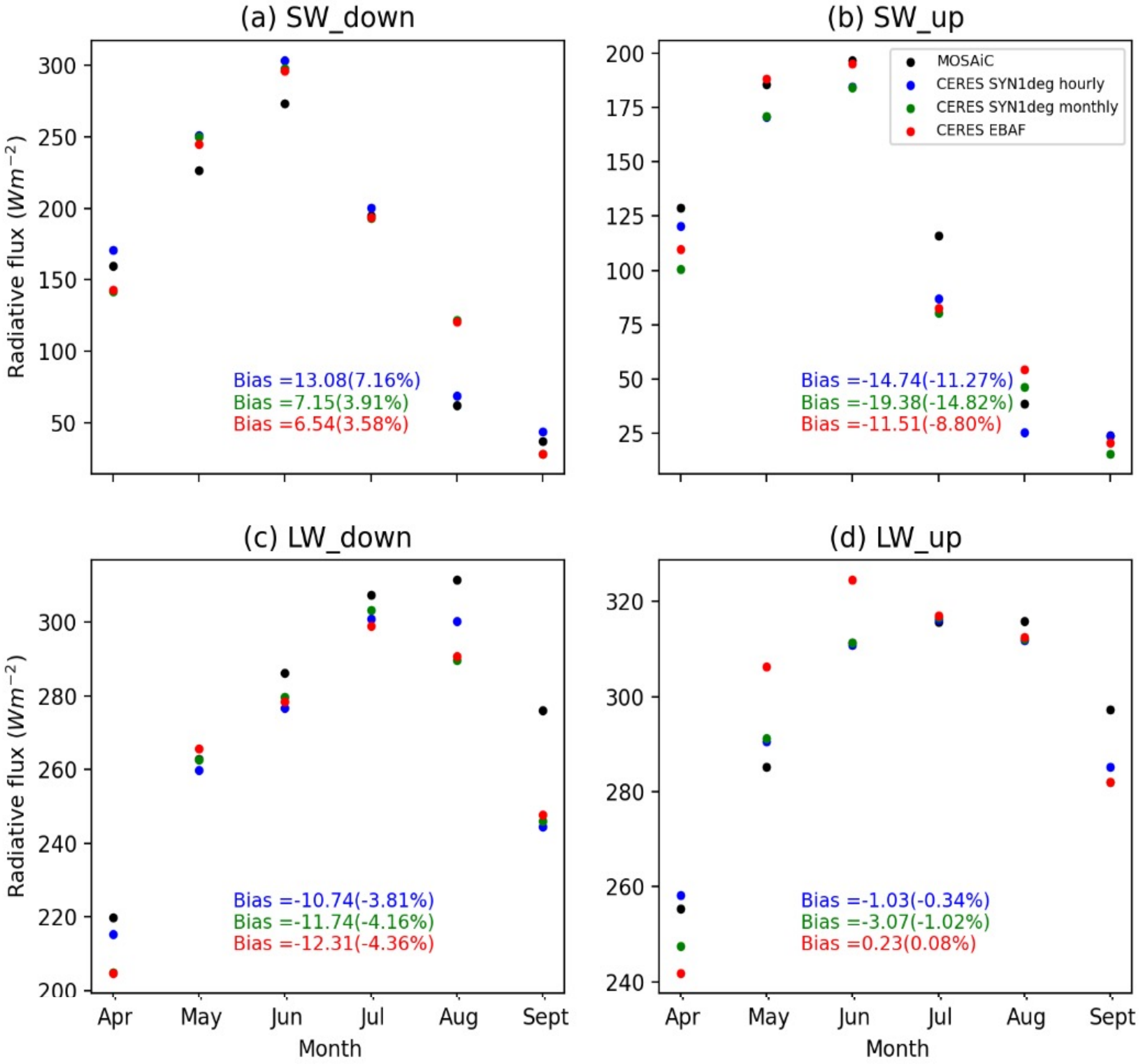
- Larger uncertainty in LW_up flux (~320W/$m^2$) occurs when the surface reaches melting point

# Influence of spatial variability on MOSAiC and CERES SYN1deg differences



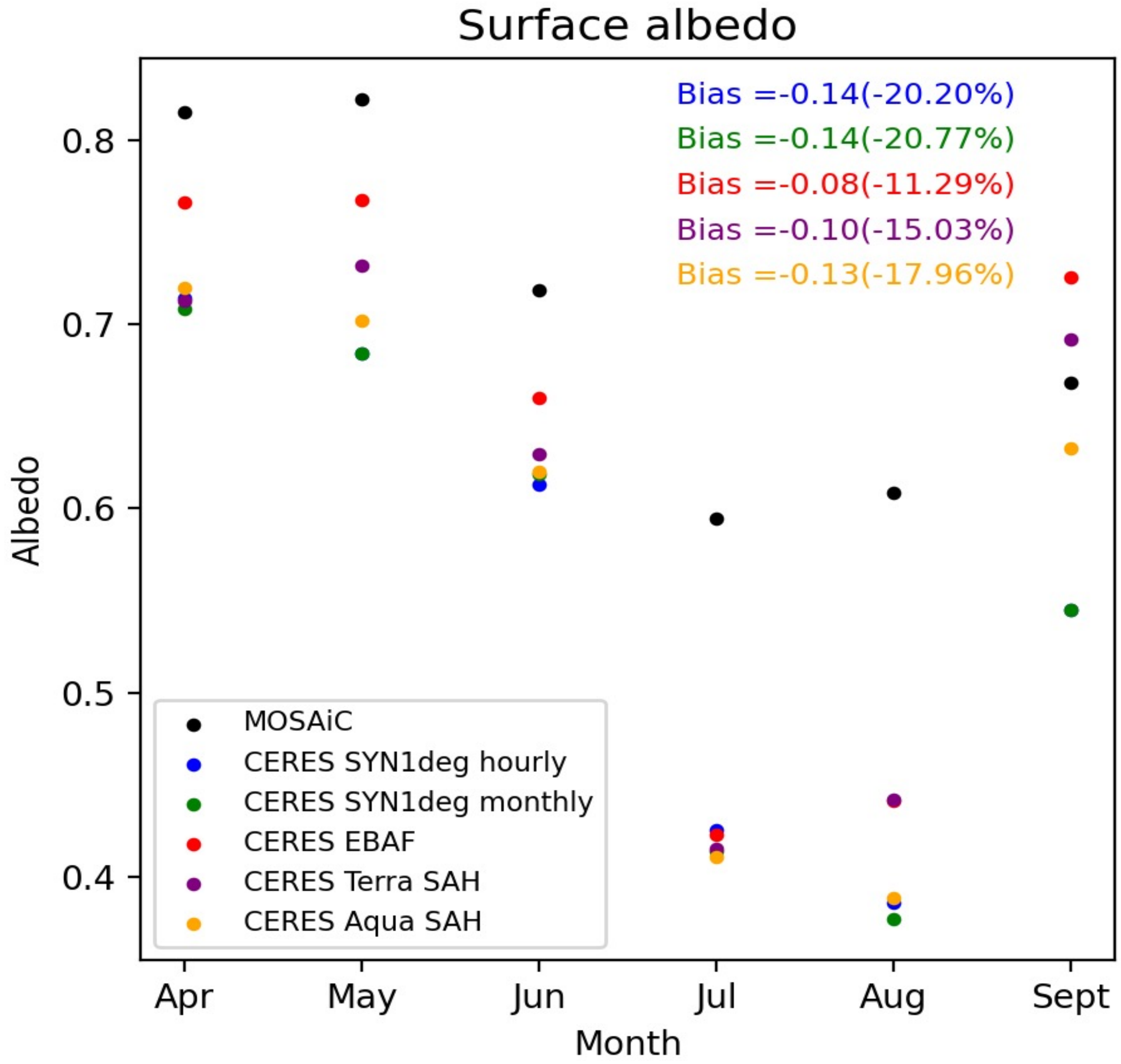

- Plots illustrate the correlation between CERES-MOSAiC differences and the magnitude of spatial variability.
- Variability (%) is quantified as the percent difference between two stations at a given hour.
- Results show a **slightly smaller** CERES-MOSAiC differences in the presence of **larger inter-surface site variability**.

# Monthly Radiative Mean fluxes : MOSAiC and CERES SYN1deg




- Monthly mean CERES-MOSAiC fluxes differ between for CERES products (e.g., SYN 1deg and EBAF).
- SFC EBAF represents the smallest biases over the 6-month period but is not always the most accurate for an individual month.

# Monthly Surface Albedo: MOSAiC and CERES SYN1deg

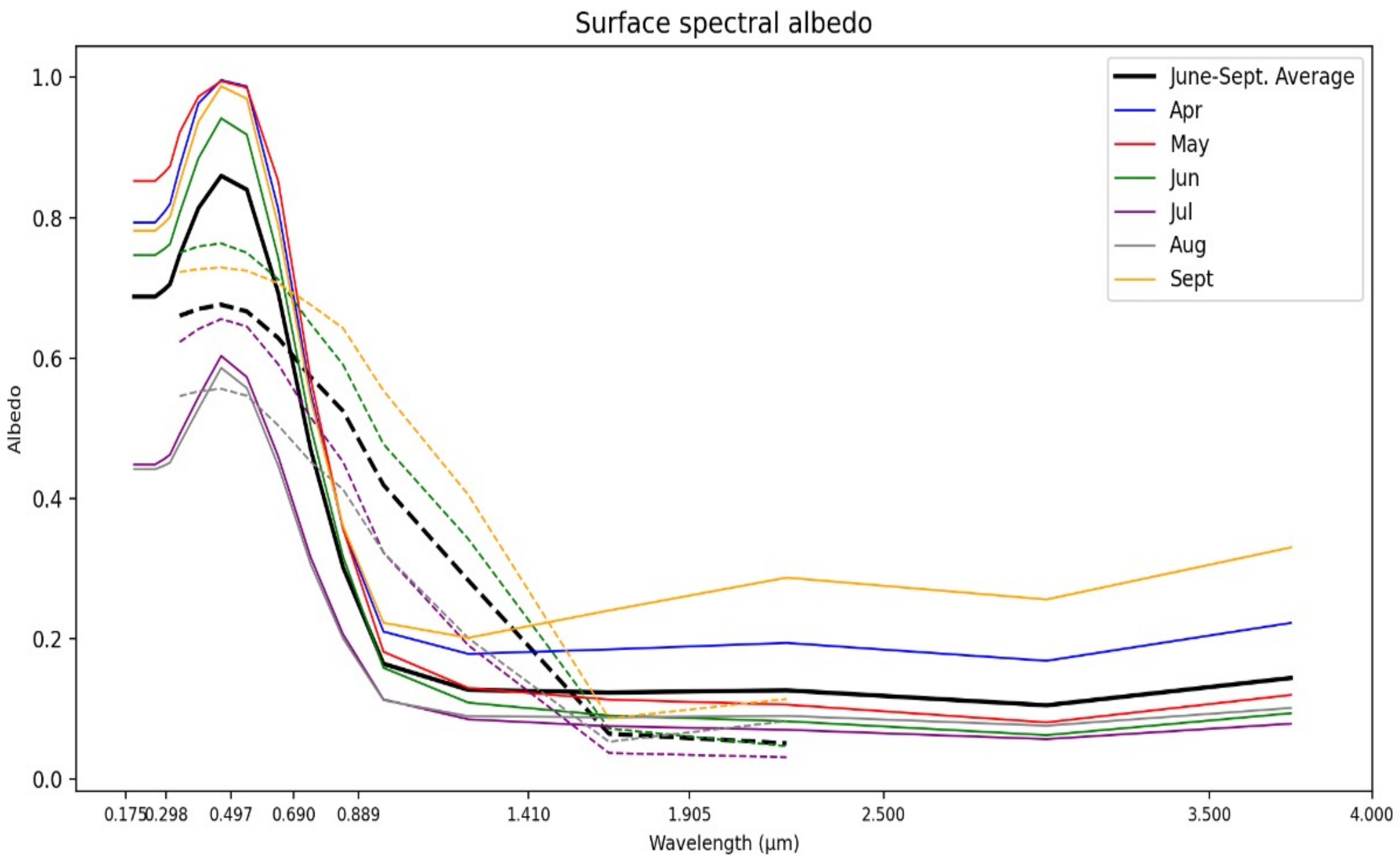



- This comparison shows the monthly mean surface albedo values over the MOSAiC domain for different CERES products and observations.
- Differences are found between the different CERES produces (e.g., SYN-1deg and EBAF)
- SFC EBAF again represents the smallest bias over the 6-month period but is not always the most accurate for an individual month.

# Spectral Surface Albedo: MOSAiC and CERES SYN1deg

Solid—CERES (Jin 2004; LUT)

Dashed—MOSAiC observations (Perovich et al. 2021)




- Comparison reveals differences in the CERES surface spectral albedo shape model and the MOSAiC observations.

# Understanding the contribution of surface albedo differences to CERES-MOSAiC differences

Radiative Transfer Experiments

Surface Albedo Effects

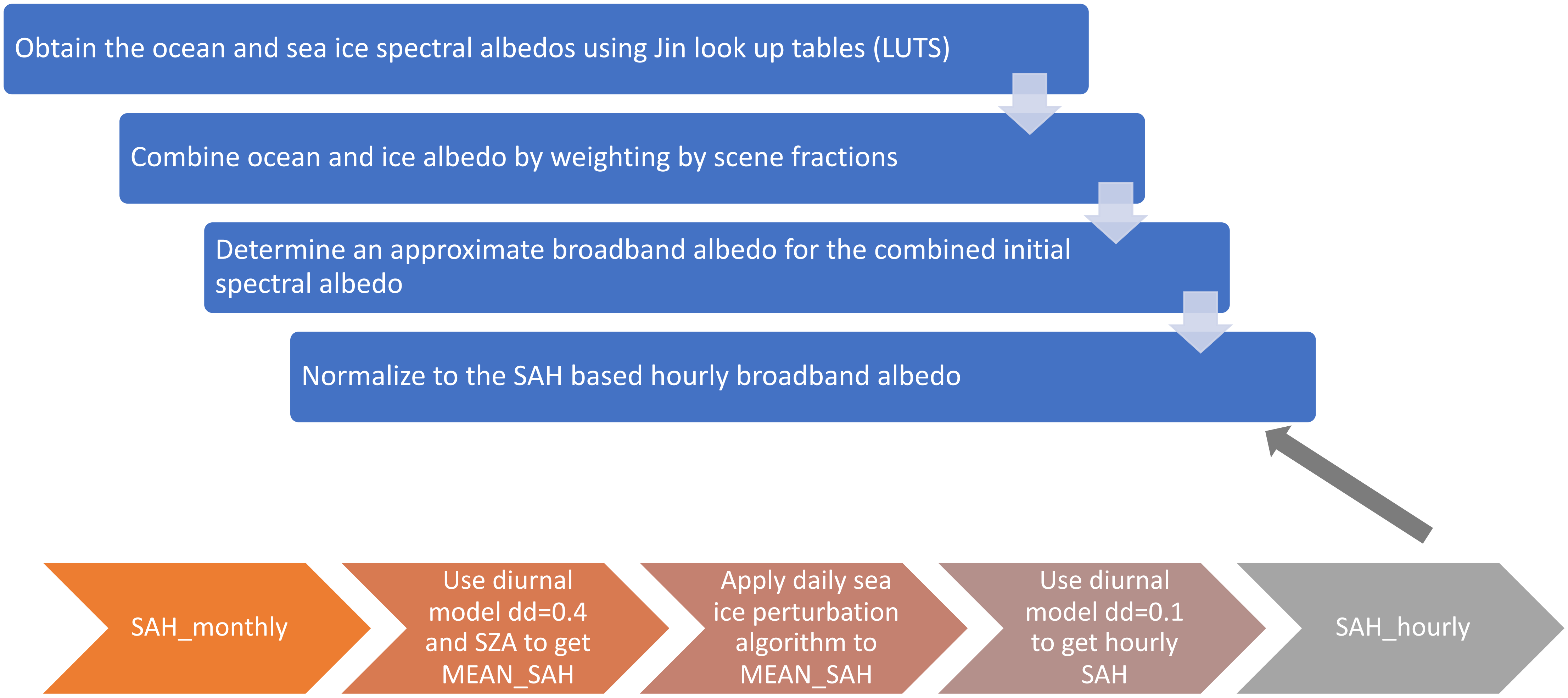
# CERES-like Fu-Liou RTM calculations

| Category | Variables | Sources |
|---|---|---|
| **General model inputs** | Number of model layers | 4 layers |
| | Solar zenith angle | TSI files |
| | Solar insolation | Daily SORCE TSI files and earth-sun distance |
| | **Solver method** | **4-stream solver for SW and LW calculation** |
| | Other information (CO2,CH4,N2O, CFCs, correction to cosSZA, etc) | Values in year 2019 |
| **Atmospheric structure inputs** | Pressure profile | MOA files (GEOS-5.4.1) |
| | Air temperature profile | |
| | Water vapor mixing ratio profile | |
| | Ozone mixing ratio profile | |
| | Surface skin temperature | |
| **Cloud inputs** | Cloud fraction, effective radius, optical depth, phase, particle size | TSI files (from MODIS) |
| **Surface inputs** | Spectral surface albedo | **JIN lookup table, daily sea ice concentration, and monthly Terra surface albedo history (SAH) map** |
| | Spectral surface emissivity | Determined by surface type |
| **Aerosol inputs** | Aerosol types and aerosol optical depth | MATCH aerosol hourly output |

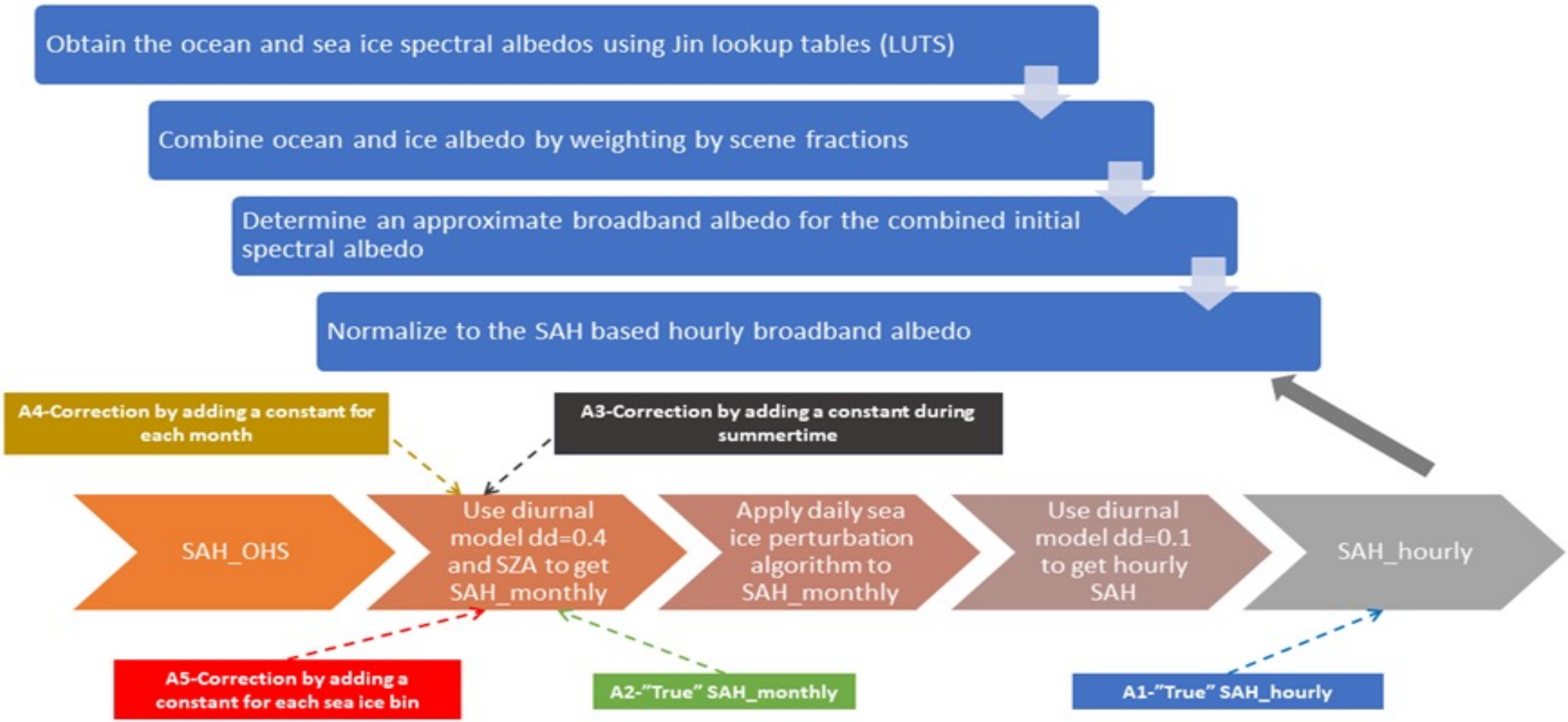
**SYN1deg Ed4**
**Gamma-weighted Two-stream approximation (GWTSA)**

**SYN1deg Ed4**
**Terra/Aqua SAH monthly map**

# CERES-Like Fu-Liou Radiative Transfer Calculations



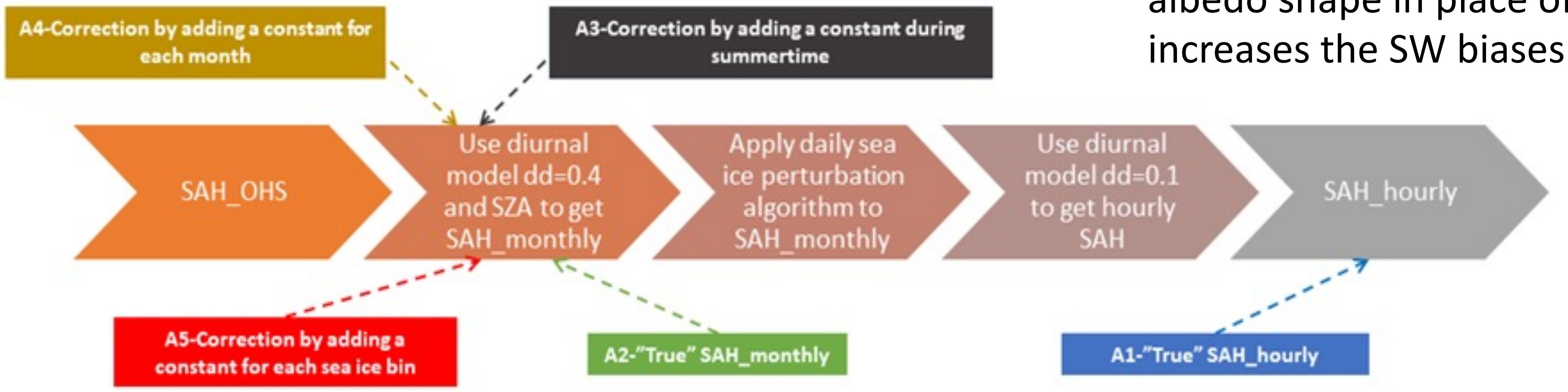
# CERES-Like Fu-Liou Radiative Transfer Calculations: Perturbation Experiments



## The SW differences between RTM and MOSAiC (W m$^{-2}$)

| Experiment | SW_down (RMSE) | SW_up (RMSE) |
|---|---|---|
| Control run | +7.88 (41.46) | -18.49 (38.31) |
| A1-"True" SAH_hourly | +17.51 (45.07) | +1.49 (32.61) |
| A2-"True" SAH_monthly | +14.37 (43.74) | -2.29 (32.27) |
| A3-correction by a constant in summer | +15.73 (44.52) | +2.46 (33.94) |
| A4-correction by adding a constant for each month | +16.22 (44.82) | +3.5 (34.48) |
| A5-Correction by adding a constant for each sea ice bin | +14.71 (44.00) | -0.24 (33.55) |
| A6-Monthly averaged spectral albedo from control run | +10.95 (44.09) | -15.11 (37.76) |
| A7-Monthly averaged spectral albedo from MOSAiC | +9.19 (42.88) | -18.04 (38.72) |

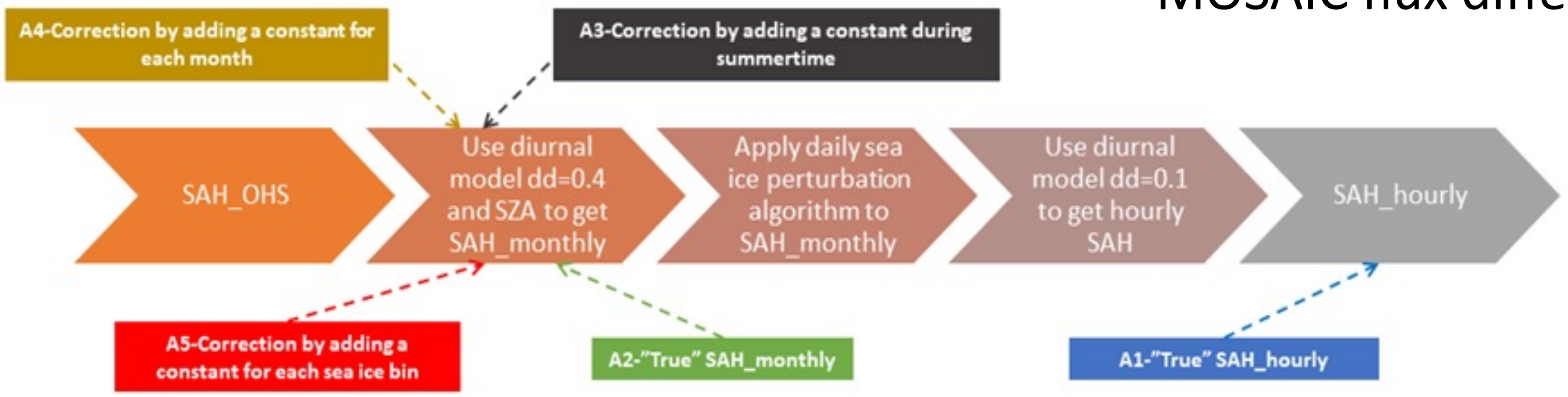
- Compared to M1 and M2, the monthly surface albedo history (SAH) bias contributes to ~**80**% of uncertainty in SW_up, while daily sea ice perturbation process accounts for ~**20%** of uncertainty
- Correcting SAH monthly map by adding a constant would be an efficient strategy to reduce SW_up biases during summertime
- The impacts of multiple reflections between clouds and highly reflective surface should be taken into consideration
- Using MOSAiC observed spectral surface albedo shape in place of the CERES-Jin LUT increases the SW biases by ~3 W m$^{-2}$



## Summary of cloud-related perturbation experiments ($Wm^{-2}$)

| Experiment | SW_down | SW_up |
|---|---|---|
| **Control run** | +7.88 (41.46) | -18.49 (38.31) |
| **A5-Correction by adding constant for each sea ice bin** | +14.71 (44.00) | -0.24 (33.55) |
| **C1-Increase cloud fraction by 1%** | +14.23 | -0.56 |
| **C2-Increase cloud fraction by 3%** | +13.67 | -0.93 |
| **C3-Remove the polar daytime cloud optical depth correction** | +5.14 | -5.51 |
| **C4-Combine C1 and C3** | +4.60 | -5.86 |
| **C5-Combin C2 and C3** | +3.97 | -6.28 |

- Each cloud property perturbation experiment is performed from the A5 experiment.
- Increasing cloud fraction and cloud optical depth improve the CERES-MOSAiC agreement for SW_down bias and degrade the agreement for SW_up.
- Both cloud properties and surface albedo differences make strong contributions to the CERES-MOSAIC flux differences.

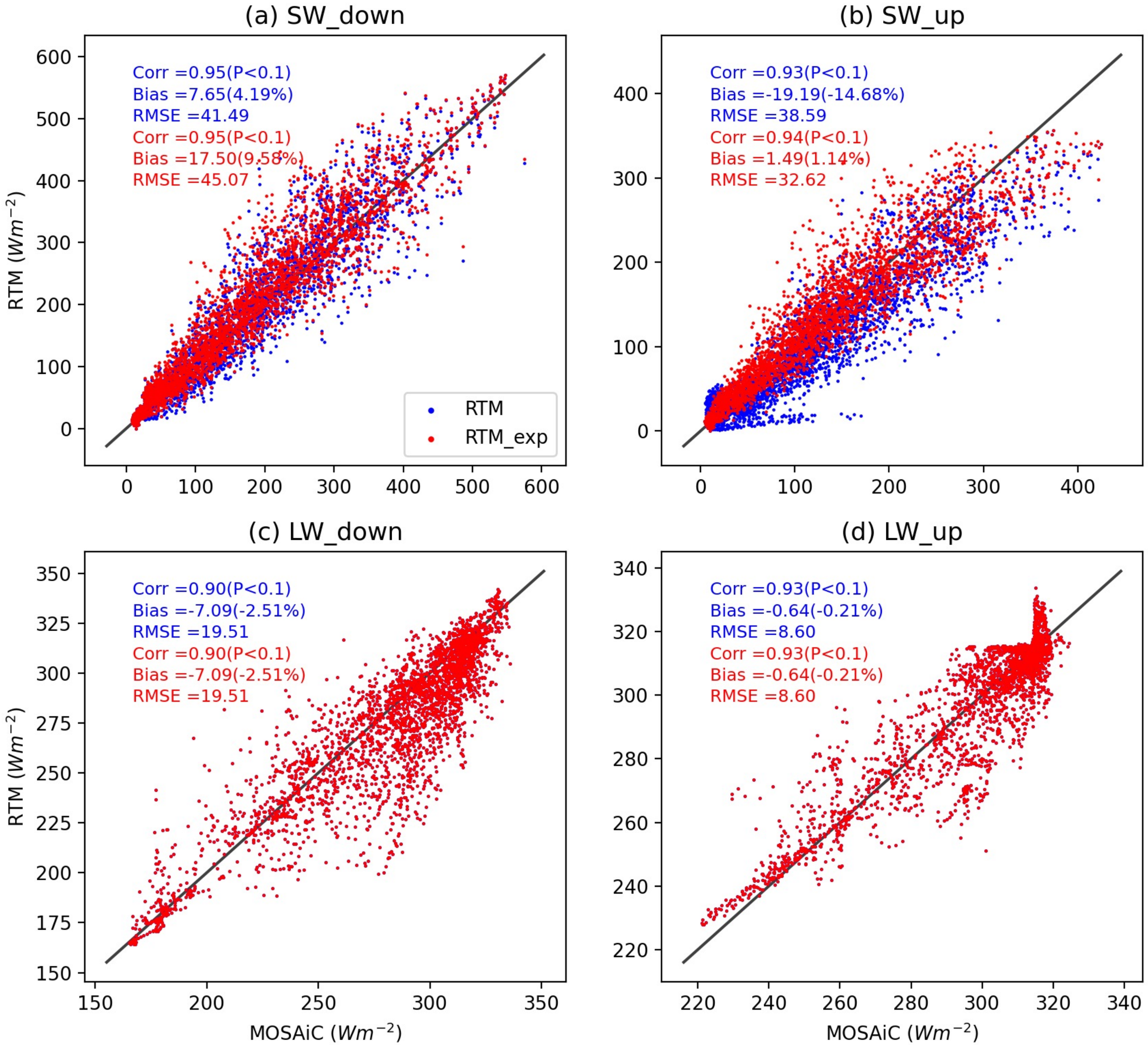


# Summary

- The SYN1deg tends to overestimate SW_down flux, but underestimate SW_up and LW_down fluxes at the surface during summertime
- The large negative bias in SW_up flux can be attributed to the underestimation of surface albedo in SYN1deg
- Correcting SAH monthly map by adding a constant number would be an efficient strategy to reduce SW biases during summertime
- It is important to consider the impacts of cloud biases (multiple reflection between clouds and reflective surface) when correct the surface albedo
- Larger uncertainty in LW_up flux (~320W/m$^2$) occurs when the surface reaches melting point (~0°C)
- The biases in surface wind and surface water vapor mixing ratio show a minor impact on SW and LW flux calculations

Photo credit: https://blogs.helmholtz.de/polarstern/en/2019/09/anchors-aweigh-for-mosaic-leg-1/

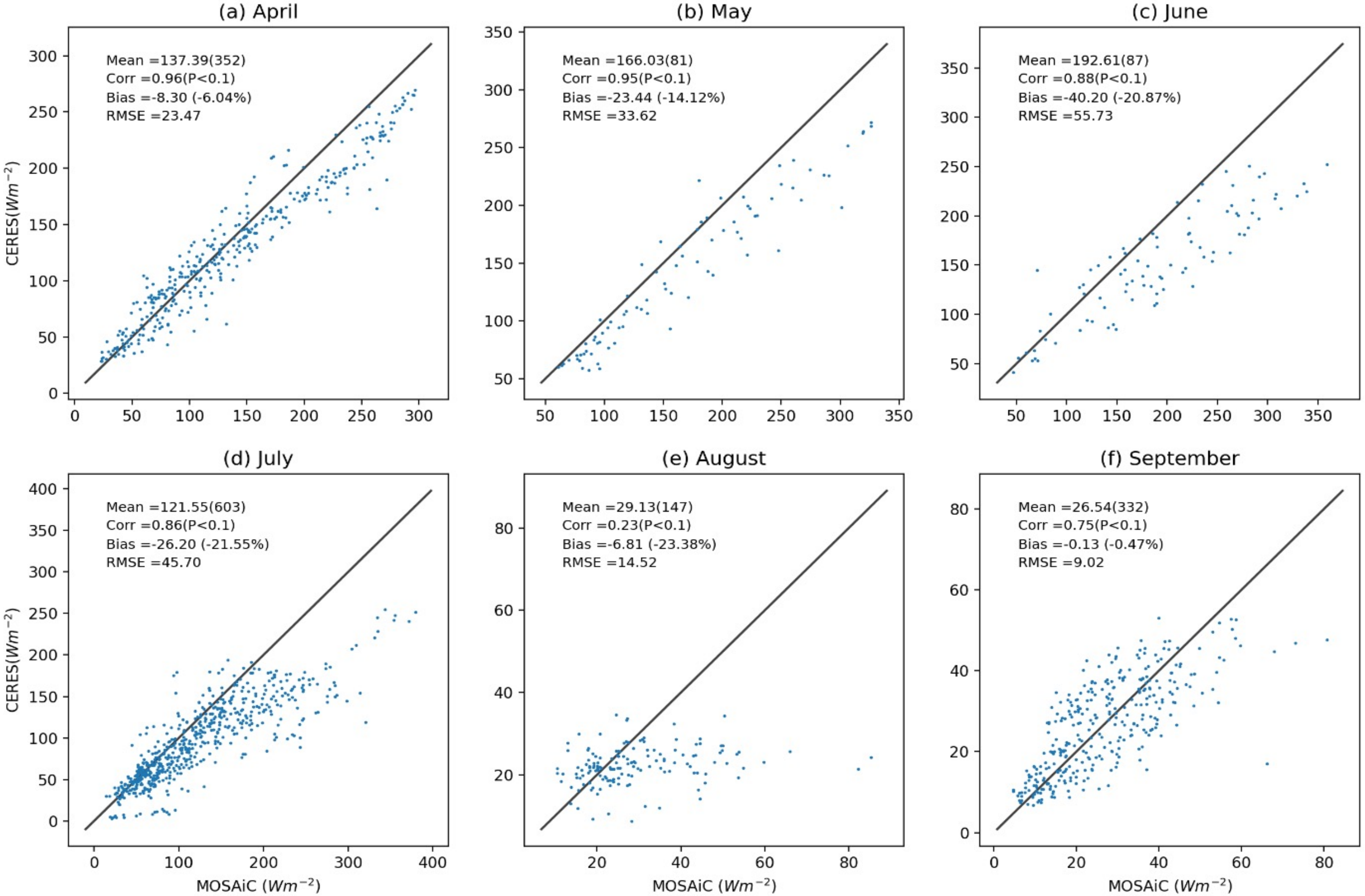
# Surface albedo calculations in the RTM – A1




- The uncertainty in SW_up flux was reduced by ~15%, while the uncertainty in SW_down flux was increased by ~8% (RMSE)

- No impacts on LW fluxes

# Monthly SW_up fluxes at the surface: MOSAiC and CERES SYN1deg




- CERES-MOSAiC differences in SW_up vary significantly from month-to-month ranging from -0.13 to -40 W $m^{-2}$.
- These differences are primarily linked to the differences in surface albedo.